Global Water Resources and Use

CHAPTER 3

All rivers run into the sea, yet the sea is not full: Unto the place from which rivers come, thither they return again.

—Ecclesiastes 1:7

FRESHWATER AND SALTWATER

Over 70% of Earth's surface is covered by water. Oceans hold about 97% of all water on Earth, while freshwater constitutes about 3%. Of the freshwater that is available, most of it is trapped in glaciers and ice caps. The rest is found (in descending order) in groundwater, lakes, soil moisture, atmospheric moisture, rivers, and streams.

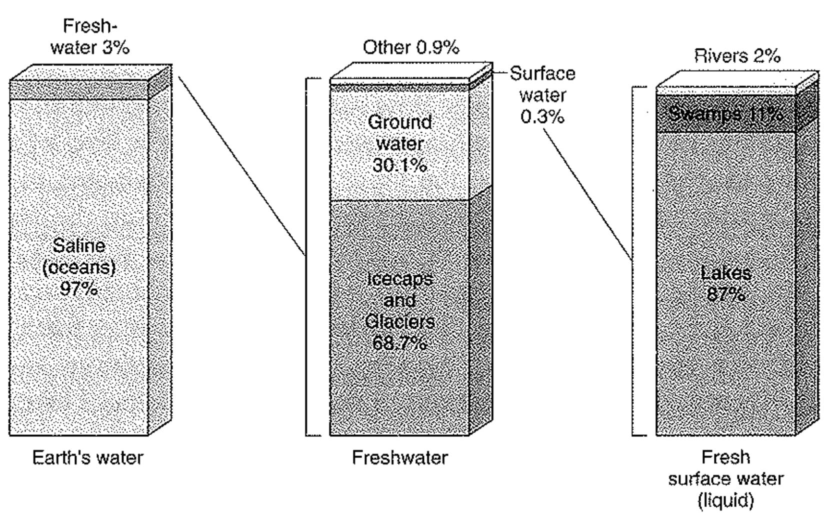


Figure 3.1 Distribution of Earth's water

Water has many unique properties:

1. Strong hydrogen bonds hold water molecules to each other.
2. The temperature of water changes slowly due to its high specific heat capacity.
3. Water has a high boiling point.

4. A lot of energy is needed to evaporate water.
5. Water dissolves many compounds.
6. Water filters out harmful UV radiation in aquatic ecosystems.
7. Water adheres to many solid surfaces.
8. Water expands when it freezes.

Most human settlements are determined by the availability of freshwater. The highest per capita supplies of freshwater are in countries with high precipitation and small populations (Iceland, Norway, and so on). Lowest per capita freshwater supplies are in areas with low rainfall and high populations (Egypt, Israel, and so on).

The use of freshwater, a limited resource, is growing at twice the rate of population growth. In the United States, the average amount of freshwater allocated per person for all purposes is approximately 500,000 gallons (1,900,000 l) per year.

LAKES

Most lakes on Earth are located in the Northern Hemisphere at higher latitudes and are generally found in mountainous areas, rift zones, areas with ongoing or recent glaciations, or along the courses of mature rivers. Processes that form lakes include: (1) tectonic uplift of a mountain range that creates a depression that accumulates water; (2) advance and retreat of glaciers that scrape depressions in the Earth's surface where water accumulates (e.g., the Great Lakes of North America); (3) salt or saline lakes that form where there is no natural outlet or where the water evaporates rapidly and the drainage surface of the water table has a higher-than-normal salt content (e.g., the Great Salt Lake, the Aral Sea, and the Dead Sea); (4) oxbow lakes formed by erosion in river valleys; and (5) crater lakes formed in volcanic craters and calderas that fill up with water more rapidly than they empty (e.g., Crater Lake in Oregon).

All lakes are temporary over geologic time scales, as they slowly fill in with sediments or spill out of the basin containing them. Changes in the level of a lake are controlled by the difference between the input and output compared to the total volume of the lake. Significant input sources are precipitation onto the lake, runoff carried by streams and channels from the lake's catchment area, groundwater channels and aquifers, and artificial sources from outside the catchment area. Output sources include evaporation from the lake, surface and groundwater flows, and any extraction of lake water by humans. Variations in climate conditions and human water requirements will create fluctuations in the lake level. Artificial lakes are constructed for hydroelectric power generation, recreational purposes, industrial use, agricultural use, or domestic water supply.

Lakes have three zones: the littoral zone, which is a sloped area close to land; the photic or open-water zone, where sunlight is abundant; and the deep-water benthic zone. The depth to which light can reach in lakes depends on turbidity, or the amount and type of suspended particles in the water. These particles can be either sedimentary (i.e., silt) or biological (e.g., algae or detritus) in origin.

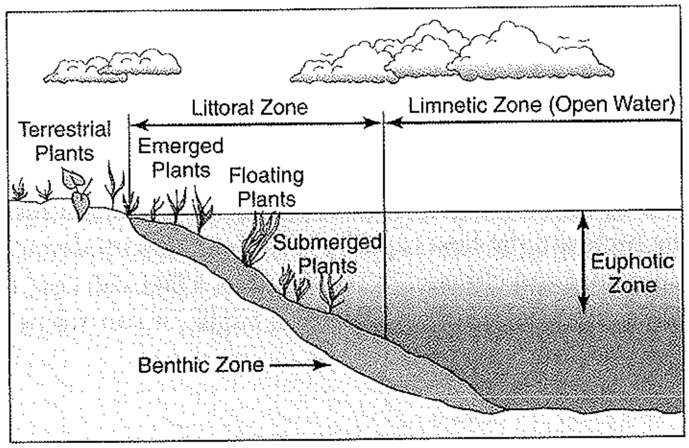


Figure 3.2 Lake zonation

A Secchi disk can be used to determine the level of turbidity or eutrophication in a lake.

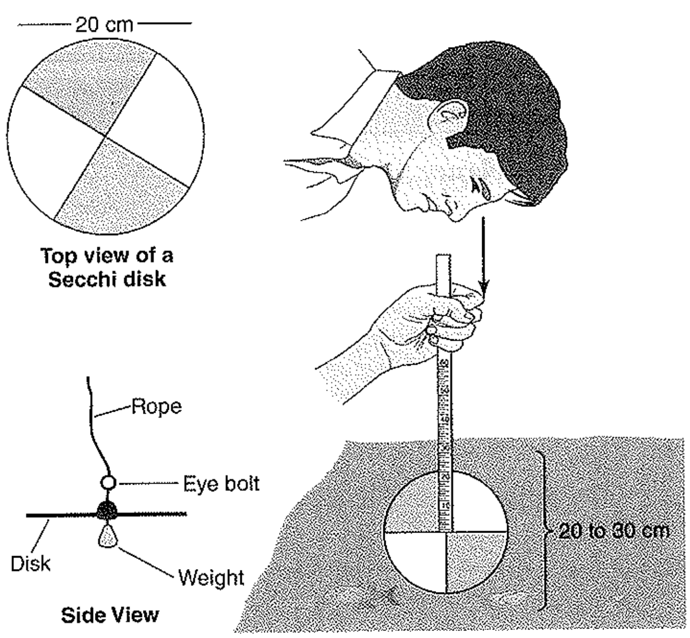


Figure 3.3 Secchi disk

The material at the bottom of a lake can be composed of a wide variety of inorganic material, such as silt or sand, and organic material, such as decaying plant or animal matter. The composition of the lake bed has a significant impact on the flora and fauna found near the lake, as it contributes to the amount and the types of nutrients available. A lake may be in-filled with deposited sediment and gradually become wetland.

Oligotrophic lakes are generally clear due to low nutrient levels and have little plant life. Mesotrophic lakes have good clarity and an average level of nutrients.

Eutrophic lakes are enriched with nutrients, resulting in large amounts of plant growth with possible algal blooms. Hypertrophic lakes have been excessively enriched with nutrients, have poor water clarity, and are subject to devastating algal blooms. These lakes usually result from human activities, such as heavy use of fertilizers or sewage outlets in the lake catchment area. Such lakes are of little use to humans and have a poor ecosystem due to decreased amounts of dissolved oxygen.

Because of the high specific heat capacity of water, lakes moderate the surrounding region's temperature and climate. In the daytime, a lake can cool the land beside it with local winds, resulting in a sea breeze; at night, it can warm it with a land breeze.

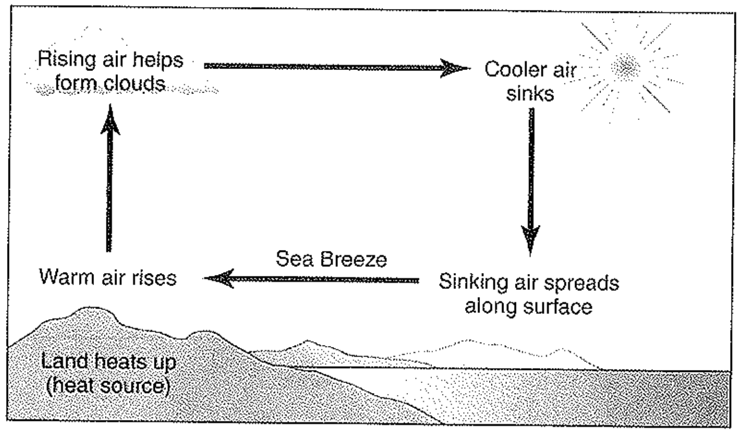


Figure 3.4 Sea breeze

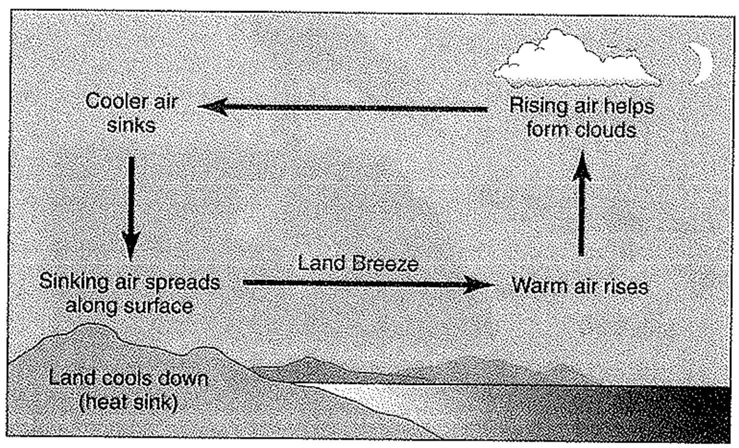


Figure 3.5 Land breeze

The stratification or layering of water in lakes is due to density changes caused by changes in temperature. The density of water increases as temperature decreases until it reaches its maximum density at about 39°F (4°C), causing thermal stratification—the tendency of deep lakes to form distinct layers in the summer months. Deep water is insulated from the sun and stays cool and denser, forming a lower

layer called the hypolimnion. The surface and water near the shore are warmed by the sun, making them less dense, so that they form a surface layer called the epilimnion.

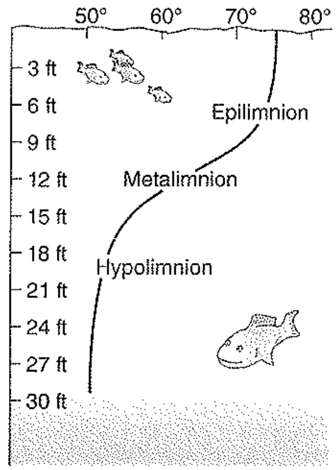


Figure 3.6 Thermal stratification

Seasonal turnover refers to the exchange of surface and bottom water in a lake or pond that happens twice a year (spring and fall). During the summer, the sun heats water near the surface of lakes, which results in a well-defined warm layer of water occurring over a cooler one (stratification). As the summer progresses, temperature differences increase between the layers, and a thin middle layer, or thermocline, develops, where a rapid transition in temperature occurs. With the arrival of fall and cooler air temperatures, water at the surface of lakes begins to cool and becomes heavier. During this time, strong fall winds move the surface water around, which promotes mixing with deeper water—a condition known as *fall turnover*. As the mixing continues, lake water becomes more uniform in temperature and oxygen level. As the winter approaches in areas where subfreezing temperatures are common, the lake surface temperatures approach the freezing mark (water is most dense at 4°C). Thus, as lake waters move toward freezing, the water sinks to the lake bottom when it reaches 4°C. Colder water remains above, perhaps eventually becoming capped by an ice layer, which further prevents the winds from stirring the water mass. With spring the surface ice begins to melt, and cold surface waters warm until they reach the temperatures of the bottom waters, again producing a fairly uniform temperature distribution throughout the lake. When this occurs, winds blowing over the lake again set up a full circulation system known as *spring turnover*.

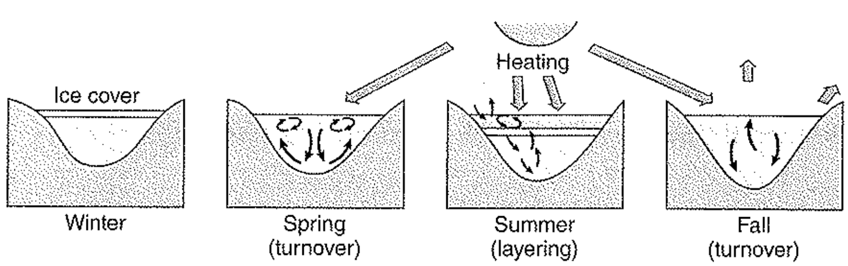


Figure 3.7 Seasonal lake turnover

WETLANDS

Wetlands include swamps, estuaries, marshes, and bogs. Wetlands are characterized by a water table that stands at or near the land surface for a long enough season each year to support aquatic plants. They are considered the most biologically diverse of all ecosystems and occur where the soil is either permanently or seasonally saturated with moisture, often covered partially or completely by shallow pools of water. The water found in wetlands can be saltwater, freshwater, or brackish. Plant life found in wetlands includes mangrove, water lilies, cattails, sedges, tamarack, black spruce, and cypress. Animal life includes many different amphibians, reptiles, birds, and mammals.

Wetlands have historically been drained for real estate development or flooded for use as recreational lakes. By 1993, half of the world's wetlands had been drained. Wetlands provide a valuable flood control function and are very effective at filtering and cleaning water.

RELEVANT TREATY

Ramsar Convention (1971): International treaty designed to address global concerns regarding wetland loss and degradation. The primary purposes of the treaty are to list wetlands of international importance and to promote their wise use, with the ultimate goal of preserving the world's wetlands. Methods include restricting access to the majority portion of wetland areas, as well as educating the public to combat the misconception that wetlands are wastelands. Also known as the Convention on Wetlands of International Importance.

AQUIFERS

An aquifer is a geologic formation that contains water in quantities sufficient to support a well or spring. Unconfined aquifers have as their upper boundary the water table. Typically (but not always), the shallowest aquifer at a given location is unconfined, meaning it does not have a confining layer between it and the surface. Unconfined aquifers usually receive recharge water directly from the surface, from precipitation or from a body of surface water (e.g., a river, stream, or lake). Confined aquifers have the water table above their upper boundary and are typically found below unconfined aquifers. The term "perched" refers to groundwater accumulating above an area of low permeability such as clay. The unsaturated zone is directly below the surface and contains some water. In the unsaturated zone, water and air fill the voids between soil or rock particles. Deeper in the ground is the zone of saturation. In the zone of saturation, the subsurface is completely saturated with water. The point where the zone of aeration meets the zone of saturation is known as the water table. Water table levels fluctuate naturally throughout the year based on seasonal variations. In addition, the depth of the water table varies.

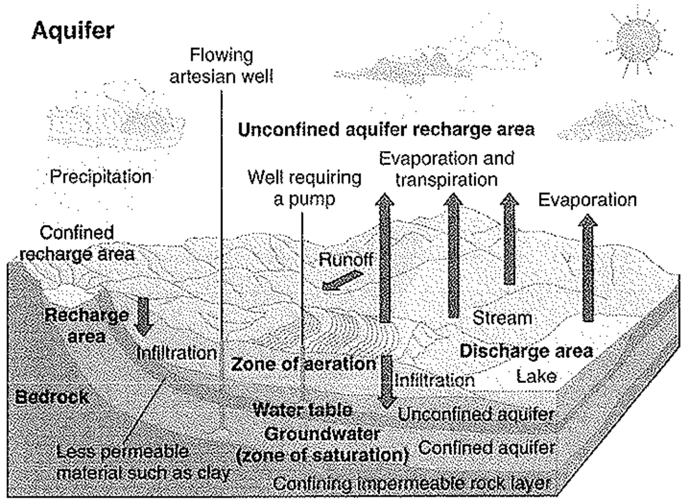


Figure 3.8 A typical aquifer

OCEANS

Approximately 71% of the Earth's surface is covered by the oceans. More than half of this area is below 10,000 feet (3,000 m) deep, with the average salt content of seawater being around 3.5%. The oceanic crust is composed of a dense, thin layer of solidified volcanic basalt as compared to the thicker but less dense continental crust, which is composed primarily of granite. The ocean floor spreads from mid-ocean ridges, where two tectonic plates adjoin. Where two plates move toward each other, one plate subducts or moves under another plate (oceanic or continental), leading to an oceanic trench.

Oceans have a significant effect on the biosphere, as oceanic evaporation is the primary source for precipitation and ocean temperatures affect climate and wind patterns. Approximately 250,000 marine life-forms are currently known, with many times that number yet to be discovered. Oceans are divided into specific zones:

Oceanic Zones

Aphotic	The depths beyond which less than 1% of sunlight penetrates.
Benthic	The ecological region at the lowest level of a body of water.
Disphotic	The zone that is dimly lit and does not have enough light penetrating from the surface to carry out photosynthesis.
Neritic	Extends from the low tide mark to the edge of the continental shelf, with a relatively shallow depth extending to about 650 feet (200 m). Generally well-oxygenated water, low water pressure, available light for photosynthesis, and relatively stable temperature and salinity levels. High biodiversity. Also known as sublittoral or photic zone.
Oceanic	The region of open sea beyond the edge of the continental shelf; includes 65% of the ocean's open water.
Pelagic	Includes all open ocean regions.
Photic (Euphotic)	The depth of the water that is exposed to sufficient sunlight for photosynthesis to occur. Biologically diverse.

Ocean Zonation

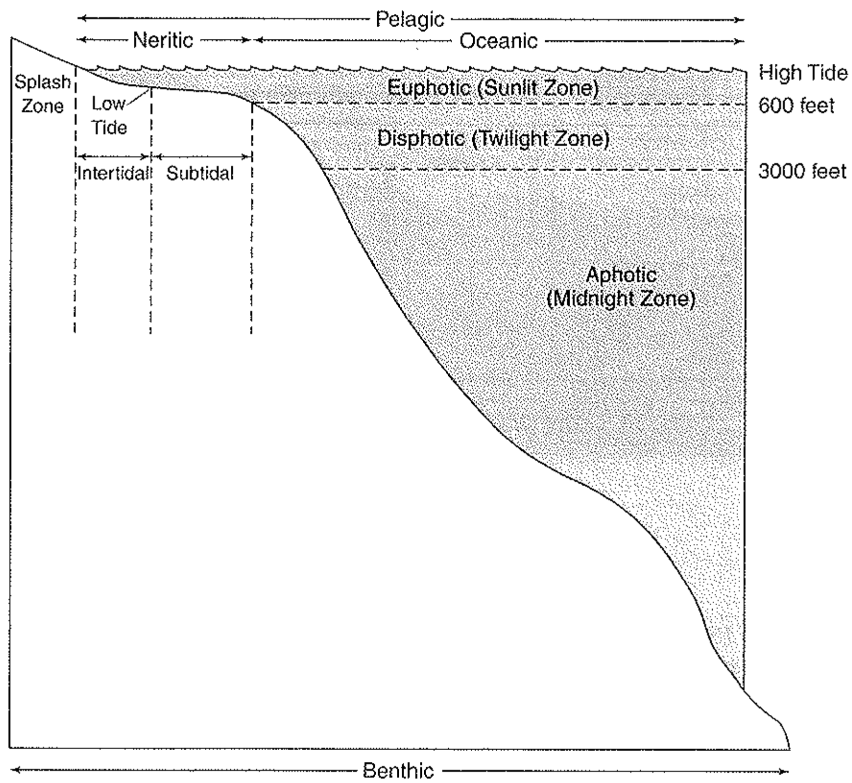


Figure 3.9 Ocean zonation

OCEAN CIRCULATION

The Northern Hemisphere is dominated by land and the Southern Hemisphere by oceans. Temperature differences between summer and winter are more extreme in the Northern Hemisphere because the land warms and cools more quickly than water. Heat is transported from the equator to the poles mostly by atmospheric air currents but also by oceanic water currents. The warm waters near the surface and colder waters at deeper levels move by convection. Changes in ocean temperatures have a direct bearing on ocean currents. During summers, a thermocline develops in ocean waters between the warm surface water and the cooler bottom water.

Surface ocean currents are driven by wind patterns that result from the flow of high thermal energy sources generated at the tropics (higher pressure) to low-energy sources in polar areas (lower pressure). They serve to distribute the heat generated near the tropics. Deep-water, density-driven currents are controlled primarily by differences in temperature and salt content. Denser, saltier water sinks, and less-dense water rises. About 90% of the ocean volume circulates due to density differences in temperature and salinities, while the remaining 10% is involved in wind-driven surface currents. In the Northern Hemisphere, north-flowing currents are warm (originating near the equator), and south-flowing currents are colder (originating from the Arctic area).

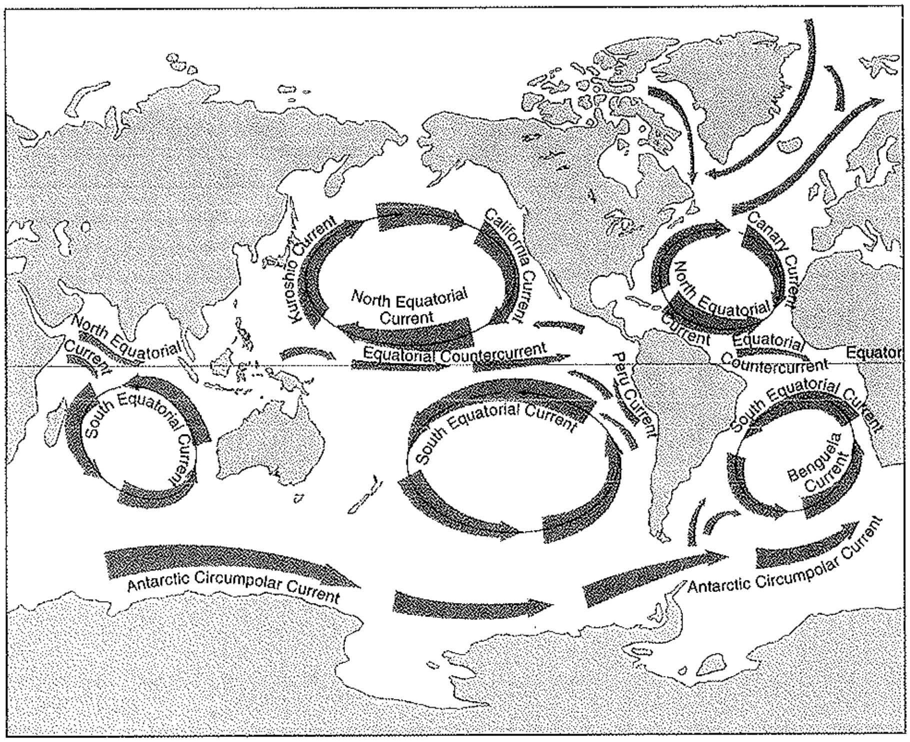


Figure 3.10 Ocean surface currents

Ocean water has warmed significantly during the past 50 years. The greatest amount of warming has occurred in the top surface layers of the ocean. The temperature of the Antarctic Southern Ocean rose by 0.31°F (0.17°C) between the 1950s and the 1980s—twice the rate for the world's oceans as a whole. Since the 1950s, the California Current that runs southward along the west coast of the United States has risen about 2.7°F (1.5°C) and has resulted in a significant decrease in plankton with resulting rippling effects within the food web. Possible reasons for dramatic increases in ocean temperatures include:

1. Significant slowing of the ocean circulation that transports warm water to the North Atlantic
2. Large reductions in the Greenland and West Antarctic ice sheets
3. Accelerated global warming due to carbon cycle feedbacks in the terrestrial biosphere
4. Decreases in upwelling
5. Releases of terrestrial carbon from permafrost regions and methane from hydrates in coastal sediments.

The Gulf Stream transports warm water from the Caribbean northward. A branch of the Gulf Stream known as the North Atlantic Drift is responsible for bringing warmer temperatures to Europe. Evaporation of ocean water in the North Atlantic results in a cooling effect and a higher salt concentration, both of which increase the density of the water. As the denser water sinks, it creates a southern circulation pattern. As glaciers in Greenland melt due to the effects of global warming, the density of this ocean water decreases due to more freshwater. This, in effect, could stall the North Atlantic Drift and bring colder temperatures and flooding to Europe.

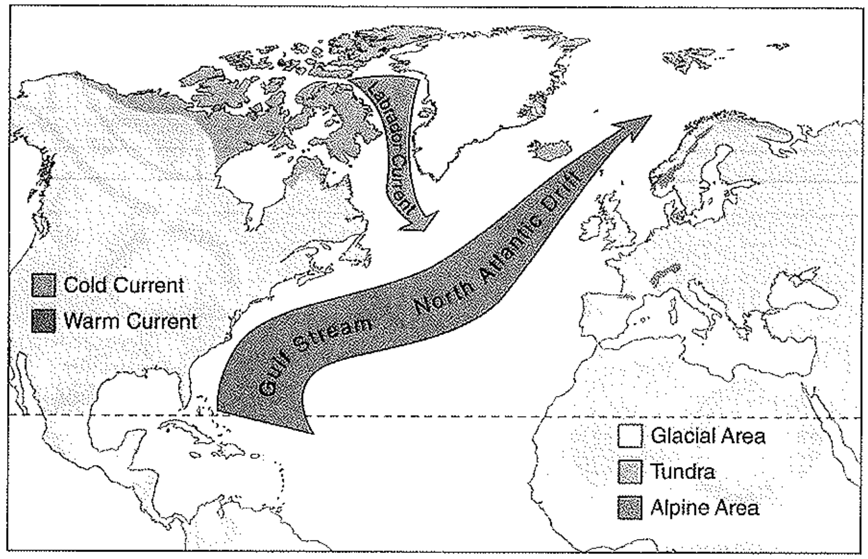


Figure 3.11 Gulf Stream

The Great Ocean Conveyor Belt

There is constant motion in the ocean in the form of a global ocean "conveyor belt" driven by thermohaline currents. These currents are density driven and are affected by both temperature and salinity. Cold, salty water is dense and sinks to the bottom of the ocean, while warm water is less dense and rises to the surface. Warm water from the Gulf Stream enters the Norwegian Sea and provides heat to the atmosphere in the northern latitudes. The loss of heat by the water in this area makes the water cooler and denser, causing it to sink. As more warm water is transported north, the cooler water sinks and moves south, making room for the incoming warm water. This cold bottom water flows south to Antarctica. Eventually, the cold bottom waters warm and rise to the surface in the Pacific and Indian oceans. It takes water about 1,600 years to move through the entire conveyor belt. The ocean conveyor belt plays an important role in supplying heat to the polar regions, and thus in regulating the amount of sea ice in these regions. Insofar as thermohaline circulation governs the rate at which deep waters are exposed to the surface, it may also play an important role in determining the concentration of carbon dioxide in the atmosphere. For more information on global warming and its effect on thermohaline circulation, refer to Chapter 11.

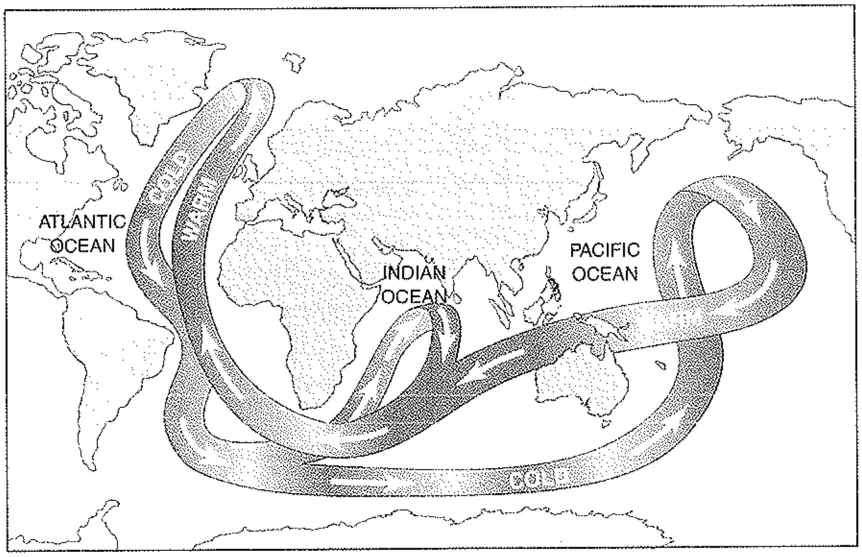


Figure 3.12 The Great Ocean Conveyor Belt

Upwellings

Upwellings occur when prevailing winds produced through the Coriolis effect, and moving clockwise in the Northern Hemisphere, push warmer, nutrient-poor surface waters away from the coastline. This surface water is then replaced by cooler, nutrient-rich deeper waters. The deeper waters contain high levels of nitrates and phosphates, which result from the decomposition and sinking of surface water plankton. When these nutrients are brought to the surface through upwelling, they supply necessary nutrients for phytoplankton, which form the base of the oceanic food chain.

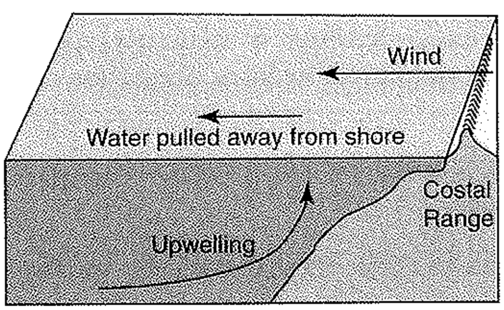


Figure 3.13 Upwelling

Ekman Transport Spiral

The Ekman transport spiral is a natural process by which wind causes movement of water near the ocean surface. Each layer of water in the ocean drags with it the layer underneath. Because of the Coriolis effect, the ocean's surface movement is 45° to the right of the direction of surface wind in the Northern Hemisphere and 45° to the left in the Southern Hemisphere. If such a current transports water away from a coast, it creates an upwelling of deep nutrient-rich sea water.

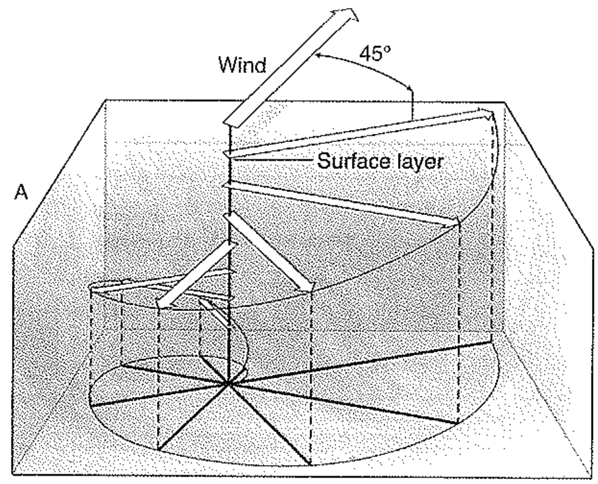


Figure 3.14 Ekman transport spiral

AGRICULTURAL, INDUSTRIAL, AND DOMESTIC USE

About 70% of freshwater is used for agriculture. Use of water for agriculture depends upon national wealth, climate, and degree of industrialization. Canada uses about 10% of its freshwater resources for agriculture, whereas India uses about 90%. Up to 70% of water intended for agriculture in developing countries may not reach crops due to seepage, evaporation, and leakage. Drip irrigation, the most efficient type of irrigation, is used on less than 1% of crops worldwide.

Advantages of Drip Irrigation

1. Increased efficiency. Almost all water reaches crops—no runoff.
2. Less energy required. Lower water demand results in less pumping costs.
3. Lower demand on aquifers or depleted water resources.
4. Crop yield increases—fertilizer is accurately applied directly to roots of plants and can be monitored. Reduces salinization and nitrate and phosphate runoff.
5. Tubing systems can be adapted to meet contours of the land and can be changed as needed.
6. Correct amounts of water means plants are neither waterlogged nor water stressed.

Industry uses about 25% of all freshwater, ranging from a high of about 75% in Europe to less than 5% in developing countries. Water used for cooling power plants is the largest sector. Water returns 60 times its economic value when used for industrial purposes rather than for agriculture.

Domestic uses of freshwater include water being used for flushing toilets, bathing, drinking, and so on. People living in developed countries use about 10 times more water for personal use than people living in less-developed countries.

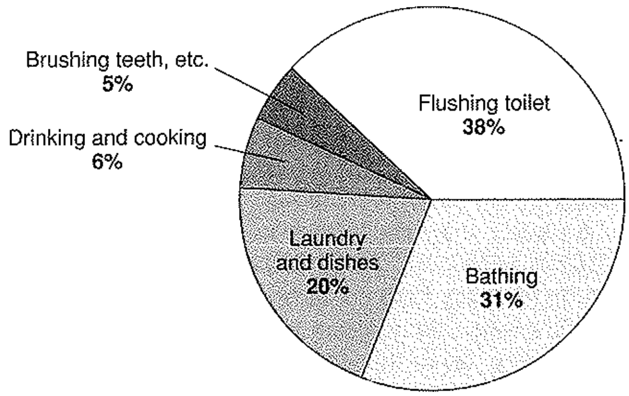


Figure 3.15 Water use

SURFACE AND GROUNDWATER ISSUES

Surface water infiltrates and percolates through the soil into aquifers—layers of porous rock, sand, and gravel where water is trapped above a nonporous layer or bedrock. The surface area in which water infiltrates into the aquifer is called the recharge zone. If pollution enters an aquifer, the aquifer is no longer a source of safe drinking water. Movement of water through aquifers is very slow. Artesian wells occur where the water breaks through to the surface. Aquifers in the United States hold 30 times more water than all U.S. lakes and rivers combined, with groundwater supplying almost 40% of all freshwater in the United States. When removal of water exceeds the recharge rate, the land sinks (subsidence). Depletion of water in aquifers also leads to sinkholes and saltwater intrusion—a condition in which seawater replaces the freshwater in the aquifer, making it unusable for human use. The region where water-saturated soil meets water-unsaturated soil is called the water table. The water table is unique to a region and can rise and fall with rainfall variations, depletion rates, and so on.

Water-Renewal Rates

Source of Water	Average Renewal Rate
Groundwater (deep)	~ 10,000 years
Groundwater (near surface)	~ 200 years
Lakes	~ 100 years
Glaciers	~ 40 years
Water in the soil	~ 70 days
Rivers	16 days
Atmosphere	8 days

CASE STUDIES

San Joaquin Valley: Groundwater-related subsidence is the sinking of land resulting from groundwater extraction. Land subsidence occurs when large amounts of ground water have been withdrawn from certain types of rocks, such as fine-grained sediments. The rock compacts because the water is partly responsible for holding the ground up. When the water is withdrawn, the rocks fall in on themselves. The desert areas of the world are requiring more and more water for growing populations and agriculture. In the San Joaquin Valley of the United States, groundwater pumping for crops has gone on for generations and has resulted in the entire valley sinking up to thirty feet.

Mexico City: A city of 22 million people, Mexico City is almost entirely dependent on exploiting groundwater for its needs. The water table in Mexico City is dropping almost six feet (2 meters) per year. Such a dramatic change in land elevation causes massive impacts on buildings and infrastructure, such as cracking and tilting.

Groundwater is considered to be one of the last "free resources," as anybody who can afford to drill can draw up water according to their ability to pump. Thus, the extraction of groundwater becomes a Tragedy of the Commons, with high economic externalities.

GLOBAL PROBLEMS

Both water shortages and rising sea levels are global problems.

Water Shortages

The rate of water consumption is growing twice as fast as the population growth rate. Freshwater shortages that result from this demand can be due to natural weather patterns that reduce rainfall, rivers changing course, flooding that contaminates existing supplies, competition for available water, overgrazing and the resulting erosion, pollution of existing supplies, and competing interests that reduce water conservation programs. Water is a limiting factor as it limits the amount of food that can be produced in a region. If food cannot be grown locally due to water shortages, then food must be imported at additional costs.

Rising Sea Levels

Rising sea level is primarily due to two factors: thermal expansion of water and the melting of ice caps and glaciers. Thermal expansion of seawater involves increasing the distance between neighboring water molecules, and this distance increases with increasing temperature. Translated over the mean depth of the ocean 2.4 miles (3.8 km), a 1-degree increase in temperature will cause a sea level rise of about 28 inches (70 cm).

During the end of the last ice age about 18,000 years ago, when global temperatures were about 10°F (5°C) warmer than they are today, sea level was about 430 feet (130 m) higher than it is today. Much of the rise was due to ice that was on land melting and filling the oceans. When ice that is floating on the water melts, it does not contribute to a rise in sea level. However, it does affect climate.

With higher sea levels and more water covering Earth's surface, more heat energy is absorbed by the water and less is reflected back into space, resulting in higher temperatures.

During the 20th century, sea levels rose 6–8 inches (15–25 cm). Approximately 1–2 inches (2–5 cm) of the rise resulted from the melting of mountain glaciers. Another 1–2 inches (15–25 cm) resulted from the expansion of ocean water that resulted from warmer ocean temperatures. Best scientific estimates indicate that sea levels will rise 7 inches (18 cm) by the year 2030 and 23 inches (58 cm) by the year 2090. Climate models have suggested that temperatures in polar regions will increase more and at a faster pace than in other areas of the world. Since 1995, more than 5,400 square miles, an area equal to Connecticut and Rhode Island combined, have broken off the Antarctic ice shelves and melted.

Several other factors contribute to rising sea levels:

1. Land buildup or erosion of mountains (isostatic adjustments)
2. Plate tectonic effects
3. Sedimentation
4. Groundwater and oil extraction
5. Changes in ocean currents and tides
6. Distribution changes in the water cycle.

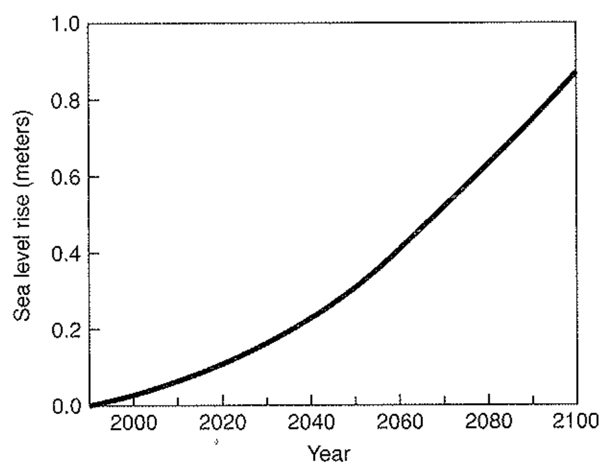


Figure 3.16 Projected rise in sea level

Wetlands are the most-impacted areas affected by rising sea levels. A 1-foot (30 cm) increase in sea level would result in up to 40% of the U.S. wetlands being destroyed. Other impacts would include: erosion of beaches and bluffs, salt intrusion into aquifers and surface waters, inundation of seawater into low-lying areas, and increased flooding and storm damage.

Much of the world's population—20%—lives in coastal regions, and half of the world's population lives within 120 miles (200 km) of the coast. Asia, Latin America, and the Caribbean have the highest percentages of people living near the coast.

CONSERVATION

Several conservation methods can be used to increase the quantity of available freshwater:

Methods to Increase Supplies of Freshwater: Description and Drawbacks

- **Changes in personal habits:** Turn off shower while washing. Wash only full loads of clothes and dishes; turn off water when brushing teeth. Check for and repair leaks around the home. Use a broom when cleaning driveways and patios. Adjust sprinklers to prevent runoff. Water at night or early morning.
- **Construct dams and reservoirs:** Interferes with fish migration and destroys natural rivers. Leakages, earthquakes, evaporation, sediment buildup, and displacement of people are also consequences. Up to 60 million people worldwide (many being indigenous minorities) have been relocated due to dam and reservoir construction.
- **Desalinate water:** Rate of production is low and is expensive (three to four times more expensive than any other process). Issues of brine disposal.
- **Drip irrigation:** Drip irrigation conserves water by reducing evaporation, but it is expensive. Most large agricultural corporations can afford it, but small, independent farmers cannot. Not suitable for annual crops.
- **Education:** Informing and educating the public on water conservation.
- **Encourage the use of recycled products that require less water to produce:** Costs of collecting products may be outweighed by savings.
- **Engineer systems to collect more runoff:** Water may be high in pollutants and expensive to reprocess.
- **Levy taxes or user fees:** Prices would go up on products. International competitiveness would be affected.
- **Line irrigation channels and cover canals:** Prevents loss of irrigation water through seepage and evaporation. Initial and maintenance costs are expensive.
- **Meter all water used:** Municipalities would recoup money on meter installation with paying less to water suppliers.
- **Plant crops that do not require as much water and xeriscaping:** Xeriscaping reduces urban runoff. Issues of market economies, crop prices and demand, weather patterns, and so on.
- **Rebates or legislation of low-flush toilets, shower restrictors, etc.:** Rebates would be offered by water companies, which, over time, would recoup costs by having to buy less water from suppliers.
- **Reduce government subsidies:** Increased water costs would be passed on to consumers and result in greater personal conservation.
- **Reprocess (recycle) water:** The public is not supportive of using reprocessed toilet water. Reprocessed water could be used for irrigation but would require separate pipeline systems. Reuse of gray water is becoming popular in new developments.
- **Seed clouds:** Water availability to other areas would be affected.
- **Tiered price scale:** Would reduce effective family income for larger families. Could be remedied through exemptions or allocated share of water per family member.

- **Use of icebergs:** Expensive and most of it would be lost before it reached final destination.
- **Use more groundwater:** If rate of use exceeds rate of recharge, then subsidence, sinkholes, and saltwater intrusion could occur.

CASE STUDIES

- **Aswan High Dam, Egypt:** Completed in the 1970s, the Aswan High Dam in Egypt was built to supply irrigation water. The water that is available is only half of what was expected due to evaporation and seepage losses in unlined canals. Several other problems were encountered. First, the elimination of nutrients onto farmlands now requires the use of expensive fertilizers. Second, the depletion of nutrients into the Mediterranean caused a decline in certain fish catches. Third, large amounts of standing water caused the proliferation of snails and ultimately resulted in a debilitating disease known as schistosomiasis, with some areas having infection rates of 80%.
- **Bangladesh:** In the 1960s, thousands of wells were dug in Bangladesh by foreign governments and humanitarian organizations in an effort to supply freshwater to the population. Shortly thereafter, arsenic compounds from the soil began to leach into the groundwater. Arsenic poisoning began to appear among the population, with millions of people showing symptoms.
- **Colorado River Basin:** Diversion of water from the Colorado River has led to water right disputes between California, Arizona, and Mexico. Dams on the Colorado River trap large quantities of silt (over 10 million metric tons per year) and reduce nutrient levels in farmlands below the dam. As a result, more fertilizer is required. Farm irrigation has resulted in high levels of sodium chloride in the alkaline soils to become incorporated in agricultural runoff. Millions of acres of once-valuable farmland are now useless due to the salt buildup in soil, a process known as salinization.
- **James Bay, Canada:** Diversion of rivers into Hudson Bay to generate electrical power has resulted in massive flooding. During one flood, up to 10,000 caribou drowned. In addition, mercury has leached out of rocks and into water, with nearby residents showing signs of mercury poisoning. The project also created expensive legal battles and created many issues with indigenous people whose land was flooded.
- **Ogallala Aquifer:** The Ogallala Aquifer underlies eight states from Texas to North Dakota. The Ogallala Aquifer used to hold more freshwater than all freshwater lakes, streams, and rivers on Earth. Due to pumping of this groundwater for agricultural, domestic, and industrial uses, many locations are experiencing water shortages.
- **Three Gorges Dam, China:** In 1949, China had no large reservoirs and only 40 small hydroelectric stations. By 1985, there were 80,000 reservoirs and 70,000 hydroelectric stations. The Three Gorges Dam required relocation of 1.2 million people.

TIP

Case studies can be brought into your essay answers to bring a historical connection to the question. Try to bring at least one case study into your essays—your score will go higher. You will also find several multiple-choice questions on the test that focus on case studies. Only the most relevant case studies are included in this book.

RELEVANT LAWS

- **Water Resources Planning Act (1965):** Provided for plans to formulate and evaluate water and related land resource projects and to maintain a continuing assessment of the adequacy of water supplies in the United States.
- **Coastal Zone Management Act (1972):** Provided funds for state planning and management of coastal areas.
- **Water Resources Development Act (1986):** Established and maintains dam safety programs.
- **National Estuary Program (1987):** Designed to identify nationally significant estuaries and to restore and protect them.

QUICK REVIEW CHECKLIST

- ☐ **Properties of Water**
  - ☐ name five physical properties of water
  - ☐ various forms and amounts of freshwater available (lakes, glaciers, ice caps, etc.)
- ☐ **Ocean Circulation**
  - ☐ causes of currents (winds, densities, temperature, thermoclines, etc.)
  - ☐ differences between Northern Hemisphere and Southern Hemisphere currents
  - ☐ causes and consequences of increases in ocean temperatures
- ☐ **Water Usage**
  - ☐ agricultural usage (various forms, advantages and disadvantages of irrigation)
  - ☐ industrial usage (relative amount compared to other uses, recycling methods)
  - ☐ domestic usage (relative amount compared to other uses)
- ☐ **Surface Water vs. Groundwater**
  - ☐ relative amount of freshwater available
  - ☐ relative renewal rates
  - ☐ pollution (current status, mitigation)
- ☐ **Rising Sea Level**
  - ☐ historical perspective
  - ☐ contributing factors
  - ☐ impact (financial and cultural)
- ☐ **Conservation**
  - ☐ name five conservation methods for industrial, agricultural, and domestic water usage

QUICK REVIEW CHECKLIST (continued)

- ☐ **Case Studies**
  - ☐ Aswan High Dam
  - ☐ Bangladesh
  - ☐ Colorado River Basin
  - ☐ James Bay
  - ☐ Ogallala Aquifer
  - ☐ Three Gorges
- ☐ **Relevant Laws**
  - ☐ Ramsar Convention
  - ☐ Water Resources Planning Act
  - ☐ Coastal Zone Management Act
  - ☐ Water Resources Development Act
  - ☐ National Estuary Program

MULTIPLE-CHOICE QUESTIONS

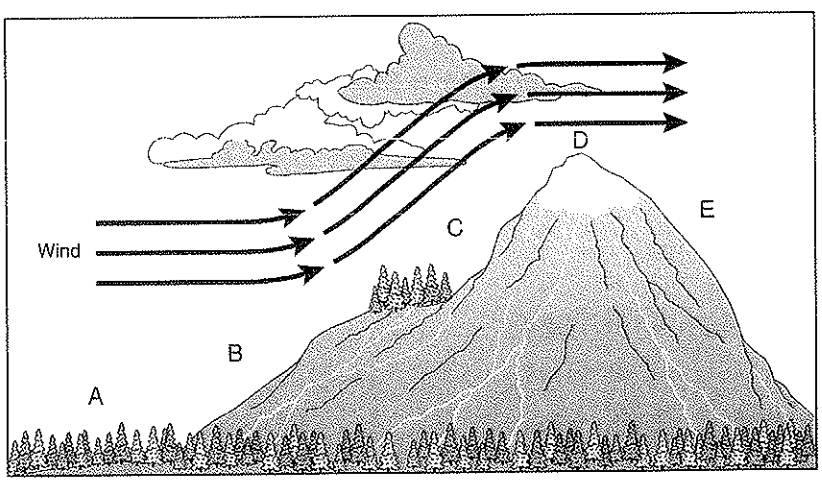
1. Water vapor returning to the liquid state is called

   (A) evaporation
   (B) transpiration
   (C) boiling
   (D) condensation
   (E) vaporization

2. The temperature at which air becomes saturated and produces liquid is called

   (A) the saturation point
   (B) the dew point
   (C) the condensation point
   (D) relative humidity
   (E) absolute humidity

Question 3 and 4 refer to the following diagram.



3. The area that would receive the most precipitation would be

   (A) *A*
   (B) *B*
   (C) *C*
   (D) *D*
   (E) *E*

4. The rain shadow effect would be located at point

   (A) *A*
   (B) *B*
   (C) *C*
   (D) *D*
   (E) *E*

5. Of the freshwater on Earth that is not trapped in snow packs or glaciers, most of it (95%) is trapped in

   (A) lakes
   (B) rivers
   (C) aquifers
   (D) dams
   (E) estuaries, marshes, and bogs

6. The primary use of freshwater is for

   (A) industry
   (B) domestic use
   (C) fishing
   (D) agriculture
   (E) landscaping

7. A mixture of freshwater and saltwater is known as

   (A) brackish water
   (B) gray water
   (C) black water
   (D) connate water
   (E) lentic water

8. A temperate lake is most likely to show thermal stratification and limited mixing of surface and deeper waters during the __________ season.

   (A) winter
   (B) spring
   (C) summer
   (D) fall
   (E) none of the above

9. Of the following methods of irrigation, the one that currently conserves the most water is

    (A) flooding fields
    (B) irrigation channels
    (C) sprinklers
    (D) drip irrigation
    (E) misters

10. The largest use for industrial water is for

    (A) cooling electrical power plants
    (B) automobile manufacturing
    (C) mining
    (D) the food and beverage industry
    (E) aquaculture

11. A country that would represent large per capita water use would be

    (A) China
    (B) India
    (C) Israel
    (D) United States
    (E) Iceland

12. When compared with the rate of population growth, the worldwide demand rate for water is

    (A) about half
    (B) about the same
    (C) about two times
    (D) about three times
    (E) about ten times

13. The U.S. per capita use of water on a daily basis is closest to
    (A) 50 gallons
    (B) 100 gallons
    (C) 1,500 gallons
    (D) 5,000 gallons
    (E) 10,000 gallons

14. Countries that are more likely to suffer from water stress would be located in

    (A) North America
    (B) South America
    (C) western Europe
    (D) the Middle East
    (E) Asia

15. What fraction of the world's population does not have access to adequate amounts of safe drinking water?

    (A) 1/2
    (B) 1/3
    (C) 1/4
    (D) 1/6
    (E) 1/10

16. Which of the following conditions may indicate an El Niño?

    (A) Sea surface warms, trade winds strengthen
    (B) Sea surface warms, trade winds weaken
    (C) Sea surface cools, trade winds strengthen
    (D) Sea surface cools, trade winds weaken
    (E) None of the above

17. Rising sea levels due to global warming would be responsible for all of the following EXCEPT

    (A) destruction of coastal wetlands
    (B) beach erosion
    (C) increased damage due to storms and floods
    (D) increased salinity of estuaries and aquifers
    (E) all would be the result of rising sea levels

18. What does La Niña bring to the southeastern United States?

    (A) Warm winters
    (B) Extremely cold winters
    (C) Hot summers
    (D) Cooler than normal summers
    (E) None of the above

19. Which of the following ocean currents flows without obstruction or barriers around Earth?

    (A) Gulf Stream
    (B) California Current
    (C) Antarctic Circumpolar Current
    (D) Aghulas Current
    (E) They all flow unimpeded.

20. Saltwater intrusion into groundwater occurs most often when

    (A) the water table near the coast drops
    (B) surface salts from irrigation water seep into the ground
    (C) storms at sea create unusually low tides
    (D) less surface water reaches the water table
    (E) salt water is pumped into aquifers to replenish water tables

FREE-RESPONSE QUESTION

The oxygen content of water is a limiting abiotic environmental factor that determines the biodiversity of an aquatic environment. An APES class visited a stream near their high school and measured several indicators of water quality.

(a) Describe a technique of determining the oxygen content of water and what it means.
(b) Briefly describe one other test that the students could have conducted to determine the water quality of the stream.
(c) Diagram a typical food web based on a freshwater stream ecosystem.

MULTIPLE-CHOICE ANSWERS AND EXPLANATIONS

1. (D) Evaporation is water changing from a liquid state to a gaseous state below the boiling point. Transpiration is water moving through a plant. Vaporization is moving from a liquid state to a gaseous state.
2. (B) The saturation point is the maximum amount of water vapor that a particular volume of air at a given temperature can hold. The condensation point is the temperature and pressure at which water vapor turns into liquid water. Absolute humidity is the mass of water vapor in a given volume of air. Relative humidity is the ratio of the actual amount of water vapor held in the atmosphere compared with the maximum amount that the air could hold and is influenced by temperature and atmospheric pressure.
3. (C) As the air lifts (orographic lifting), it becomes cooler. Cooler air holds less water vapor. At location *C*, the air is holding the maximum amount of water vapor. Given the fact that the temperature has decreased, it would receive the maximum amount of rain. At the top of the mountain at location *D*, much of the water vapor has been depleted from the air.
4. (E) Point *E* is on the leeward side of the mountain. This side receives little precipitation because most of the rain has been deposited on the windward side. The leeward side is experiencing the rain shadow effect.
5. (C) The oceans hold 98% of all water on Earth. Freshwater only makes up 2%. Of that 2%, 90% of it is trapped in ice and snow, which is rapidly melting due to global warming. Of the freshwater left, the majority is found in groundwater, with the remaining 3% of freshwater found in lakes, rivers, and streams. Of the total amount of water on Earth, only 0.01% is located in lakes, rivers, and streams.
6. (D) Agriculture uses about 70% of all freshwater. Use for agriculture depends upon national wealth, climate, and degree of industrialization. Industry uses about 25% of all freshwater, with Europe using the most and developing countries using the least. Water used for cooling of power plants is the largest sector.
7. (A) Gray water is sewage water that does not contain toilet wastes. Black water is sewage that does contain toilet wastes. Connate water is also known as fossil water and is water that has been trapped within sediment or rock structures at the time the rock was formed. Lentic water is the standing water of lakes, marshes, ponds, and swamps.

8. (C) During the summer, the surface water warms up much faster than the deep water. The warmer surface water is less dense than the cooler, deep water, so it stays on the surface. The wind mixes the surface water but only near the surface. The lake tends to become stratified, with a warmer upper layer or epilimnion and a cooler lower layer or hypolimnion. The boundary between these layers is called the thermocline.
9. (D) Drip irrigation can increase yields and decrease water requirements and labor. It provides the plant with continuous, near-optimal soil moisture by conducting water directly to the plant. It saves water because only the plant's root zone receives moisture.
10. (A) Industry used about 25% of all freshwater, ranging from 75% in Europe to less than 5% in developing countries.
11. (D) Highest per capita supplies of freshwater are in countries with high rainfall and low populations (Iceland, Norway, and so on). These water-rich countries have low water withdrawals. Remember, *per capita* means "per person."
12. (C) Since populations are increasing and increased populations result in higher levels of pollution and since freshwater sources are finite, the amount of freshwater per person is decreasing each year.
13. (C) In the United States, renewable or replacement water averages 2.4 million gallons (9 million L) per person per year. The average amount withdrawn from water supplies in the United States is about 500,000 gallons (1.9 million L) per person per year (1,500 gallons [5,700 L] per day).
14. (D) Areas that do not receive as much precipitation include polar regions (cold air cannot hold as much water as warmer air), midcontinental areas (they are too far from oceans and the clouds have released much of their moisture before they reach inland), subtropical deserts (air masses are subsiding), and the leeward sides of mountains near coastal regions (rain shadow effect).
15. (D) It is estimated that over 1 billion people lack access to safe drinking water. A child dies every 8 seconds worldwide from contaminated water sources (over 5 million children each year).
16. (B) The warm waters of El Niño (ENSO) encompass the central Pacific region. Normally, a warm pool of ocean water builds up in the western equatorial Pacific Ocean. When air pressure patterns weaken, though, the trade winds decrease or even reverse direction. This causes the warmer water to move eastward.
17. (E) Sea levels are rising and are caused by both natural and human factors. A 0.5-inch (1 cm) rise in sea level erodes beaches about 3 feet (1 m) horizontally. It is predicted that within 100 years, there will be a net loss of up to 43% in coastal wetlands due to rising sea levels.
18. (A) La Niña can bring warm winters to the southeast and cooler-than-normal winter temperatures to the northwest United States. It is the cold counterpart of El Niño. La Niña's strong easterly winds bring cold ocean water to the surface in the eastern Pacific and causes increased rainfall in the western Pacific. The jet stream rather than coming through the Pacific Northwest is diverted over Alaska and into the Great Lakes region.
19. (C) The Antarctic Circumpolar Current is the most powerful ocean current system on Earth and exerts a strong influence on climate. It circles Earth in the southern hemisphere and connects the three great ocean basins—Atlantic, Indian, and Pacific. Unlike in the Northern Hemisphere, there are no landmasses to break up this large, continuous stretch of water.

20. (A). Normally, the groundwater underlying coastal regions has an upper layer of freshwater with salt water beneath it. The layering occurs because rain, falling as freshwater, is less dense than salt water. When freshwater is withdrawn at a faster rate than it can be replenished, a drawdown of the water table occurs, with a resulting decrease in the overall hydrostatic pressure. When this happens near an ocean coastal area, saltwater from the ocean intrudes into the freshwater aquifer.

FREE-RESPONSE ANSWER

(a) Biological oxygen demand (BOD) is a measure of the oxygen used by microorganisms to decompose organic wastes. If there is a large quantity of organic waste in the water supply, bacterial counts will be high. Therefore, the demand for oxygen will be high, resulting in a high BOD level. As the waste is consumed or dispersed through the water, BOD levels will begin to decline. Nitrates and phosphates in a body of water can also contribute to high BOD levels. Nitrates and phosphates are plant nutrients and can cause plant life and algae to grow quickly. When plants grow quickly, they also die quickly. This contributes to the organic waste in the water, which is then decomposed by bacteria—resulting in a high BOD level. When BOD levels are high, dissolved oxygen (DO) levels decrease because the oxygen that is available in the water is being consumed by the bacteria. Because less dissolved oxygen is available in the water, fish and other aquatic organisms may not survive.

The BOD test takes five days to complete and is performed using a dissolved oxygen test kit. The BOD level is determined by comparing the DO level of a water sample taken immediately with the DO level of a water sample that has been incubated in the dark for five days. The difference between the two DO levels represents the amount of oxygen required for the decomposition of any organic material in the sample and is a good approximation of the BOD level.

BOD levels of 1–2 ppm are indicative of good water quality and there will not be much organic waste present in the water supply. A water supply with a BOD level of 3–5 ppm is considered moderately clean. In water with a BOD level of 6–9 ppm, the water is considered somewhat polluted because there is usually organic matter present, and bacteria are decomposing this waste. At BOD levels of 10 ppm or greater, the water supply is considered very polluted with organic wastes. At these BOD levels, organisms that are more tolerant of lower dissolved oxygen may appear and become numerous (such as leeches and sludge worms). Organisms that need higher oxygen levels (like caddis fly larvae and mayfly nymphs) will not survive.

Notable points:

Using BOD as a measure of oxygen content.

Explaining what BOD means.

Mentioning what factors determine or can affect BOD levels.

Explaining how BOD is determined.

Explaining how BOD levels affect water quality.

(b) (1) Turbidity is a measure of suspended and colloidal particles, including clay, silt, organic and inorganic matter, algae and microorganisms in a water sample. It is caused by soil erosion, excess nutrients, various wastes and pollutants, and the action of bottom-feeding organisms that stir up sediments in the water. Turbidity is measured electronically by quantifying the degree to which light is traveling through a water column. The light is scattered by the

Although only 1 test was required, 3 common tests are included here.

Other suitable tests could have been chosen.

Choosing an appropriate test.

Explaining what the test measures.

Explaining properly how the test is conducted.

Explaining how the results of the test affect water quality.

suspended organic and inorganic particles. The scattering of light increases with a greater suspended load of particles.

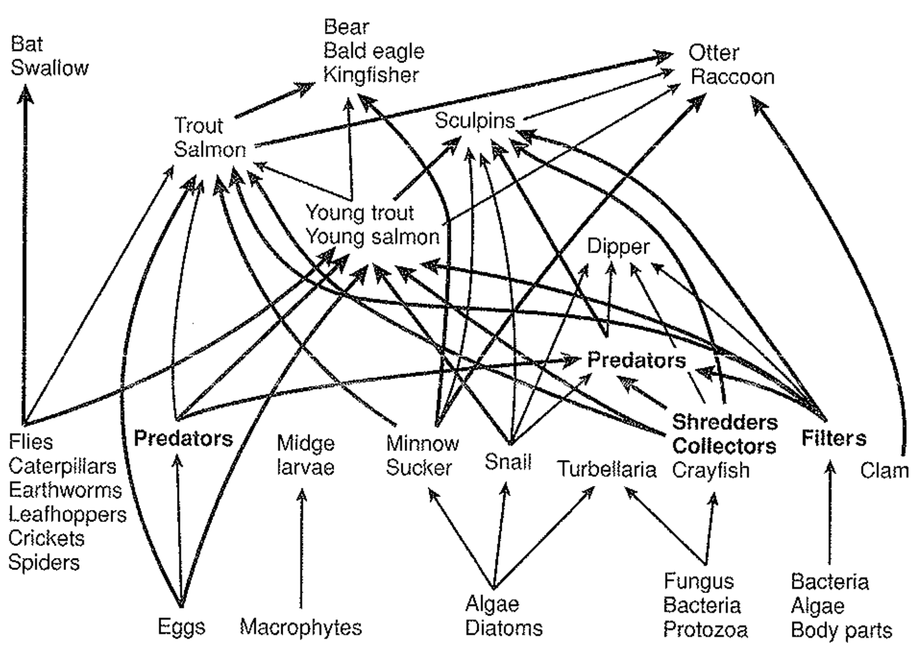
When turbidity is high, water loses its ability to support a diversity of aquatic organisms. Oxygen levels decrease in turbid water as the result of heat absorption by the particles. Greater concentrations of suspended particles also decrease photosynthesis rates. Suspended solids can clog fish gills, reduce growth rates, reduce disease resistance, and prevent egg and larval development. Settled particles can accumulate and smother fish eggs and aquatic insects on the river bottom, suffocate newly hatched insect larvae, and make river bottom microhabitats unsuitable for mayfly nymphs, stonefly nymphs, caddis fly larvae, and other aquatic insects.

(2) Nitrate (NO_3^-) and nitrite (NO_2^-) ions are inorganic forms of nitrogen in the aquatic environment. Nitrate along with ammonia are the forms of nitrogen used by plants. Nitrates and nitrites are formed through the oxidation of ammonia by nitrifying bacteria, a process known as nitrification. In turn, these ions are converted to other nitrogen forms by denitrification and plant uptake. Nitrogen in its various forms is usually more abundant than phosphorus in the aquatic environment; therefore, nitrogen rarely limits plant growth as phosphorus does. Sources of nitrates include the atmosphere, inadequately treated wastewater from sewage treatment plants, agricultural runoff, storm drains, and poorly functioning septic systems.

(3) pH: pH is measured on a log scale of 0 to 14 and measures the concentration of hydrogen ions (H^+). Pure distilled water is considered neutral with a pH of 7. The strongest acid has a pH of 0, and the strongest base has a pH of 14. For every 1 unit of pH change, there is a tenfold change. Many species of fish and aquatic plants are sensitive to changes in pH. Acidic lakes and streams can cause leaching of heavy metal ions into the water. pH measurements are determined by using either electronic pH meters or pH paper that contains organic dyes sensitive to narrow pH ranges.

(c)

A sample food web is included here ONLY for reference. The student does NOT need to include any of the organisms listed here to receive full credit. However, the food web that is drawn must be correct.



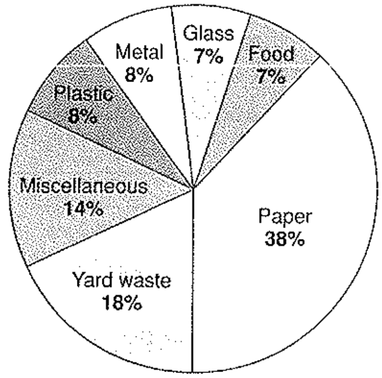


Figure 9.3 Amounts and types of municipal solid wastes (MSW) in the U.S.

Disposal and Reduction

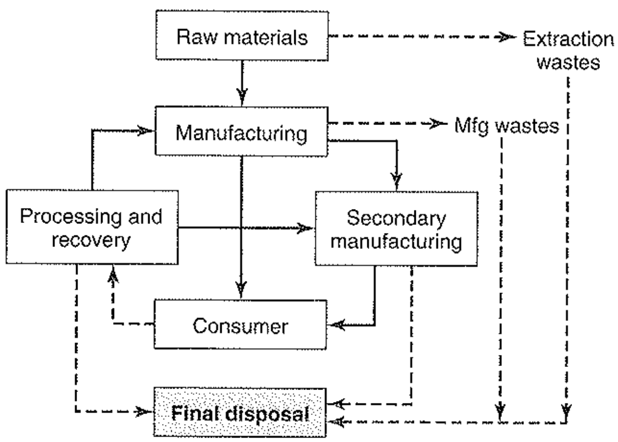


Figure 9.4 Solid waste flow diagram

BURNING, INCINERATION, OR ENERGY RECOVERY

Pros

- Heat can be used to supplement energy requirements.
- Reduces impact on landfills.
- Mass burning is inexpensive.
- What is left is 10% to 20% of original volume.
- U.S. incinerates 15% of its wastes.
- France, Japan, Sweden, and Switzerland incinerate > 40% of their wastes and use the heat to generate electricity.

Cons

- Air pollution including lead, mercury, NO_x, cadmium, SO_2, HCl, and dioxins.
- Sorting out batteries, plastics, etc. is expensive.
- No way of knowing toxic consequences.
- Ash is more concentrated with toxic materials.
- Initial costs of incinerators are high.
- Adds to acid precipitation and global warming.

COMPOSTING

Pros

- Creates nutrient-rich soil additive.
- Aids in water retention.
- Slows down soil erosion.
- No major toxic issues.

Cons

- Public reaction to odor, vermin, and insects.
- Not in my backyard (NIMBY).

REMANUFACTURING

Pros

- Recovers materials that would have been discarded.
- Beneficial to inner cities as an industry because material is available and jobs are needed.

Cons

- Toxic materials may be present (CFCs, heavy metals, toxic chemicals, and so on).

DETOXIFYING

Pros

- Reduces impact on the environment.

Cons

- Expensive.

EXPORTING

Pros

- Gets rid of problem immediately.
- Source of income for poor countries.

Cons

- Garbage imperialism or environmental racism.
- Long-term effects not known.
- Expensive to transport.

LAND DISPOSAL—SANITARY LANDFILLS

Pros

- Waste is covered each day with dirt to help prevent insects and rodents.
- Plastic liners, drainage systems, and other methods help control leaching material into groundwater.
- Geologic studies and environmental impact studies are performed prior to building.
- Collection of methane and use of fuel cells to supplement energy demand.

- Use of anaerobic methane generators reduces dependence on other energy sources.

Cons

- Rising land prices. Current costs are $1 million per hectare.
- Transportation costs to the landfill.
- High cost of running and monitoring landfill.
- Legal liability.
- Suitable areas are limited.
- NIMBY.
- Degradable plastics do not decompose completely.

LAND DISPOSAL—OPEN DUMPING

Pros

- Inexpensive.
- Provides a source of income to the poor by providing recyclable products to sell.

Cons

- Trash blows away in the wind.
- Vermin and disease.
- Leaching of toxic materials into the soil.
- Aesthetics.

OCEAN DUMPING

Pros

- Inexpensive.

Cons

- Debris floats to unintended areas.
- Marine organisms and food webs are impacted.
- Illegal in the United States.

RECYCLING

Pros

- Turns waste into an inexpensive resource.
- Reduces impact on landfills.
- Reduces need for raw materials and the costs associated with it.
- Reduces energy requirements to produce product. For example: recycling aluminum cuts energy use 95% and producing steel from scrap reduces energy requirements 75%.
- Reduces dependence on foreign oil.
- Reduces air and water pollution.
- Bottle bills provide economic incentive to recycle.

Cons

- Poor regulation.
- Fluctuations in market price.

- Throwaway packaging is more popular.
- Current policies and regulations favor extraction of raw materials. Energy, water, and raw materials are sold below real costs to stimulate new jobs and the economy.

REUSE

Pros

- Most efficient method of reclaiming materials.
- Industry models already in place—auto salvage yards, building materials, and so on.
- Refillable glass bottles can be reused 15 times.
- Cloth diapers do not impact landfills.

Cons

- Cost of collecting materials on a large scale is expensive.
- Cost of washing and decontaminating containers is expensive.
- Only when items are expensive and labor is cheap is reuse economical.

RELEVANT LAWS

Solid Waste Disposal Act (1965): First federal law that required environmentally sound methods for disposal of household, municipal, commercial, and industrial wastes.

Resource Conservation and Recovery Act (1976): Encouraged states to develop comprehensive plans to manage nonhazardous industrial solid and municipal wastes. Set criteria for municipal landfills and disposal facilities, and prohibited open dumping of solid wastes.

Toxic Substances Control Act (TOSCA) (1976): Gave the EPA the authority to track industrial chemicals produced within or imported into the United States. Allows the EPA to ban the manufacture or importation of chemicals that pose risks.

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA—Superfund) (1980): Provided authority for the federal government to respond to releases or possible releases of hazardous substances that could threaten public health and/or the environment. Established rules for closed and abandoned hazardous waste sites. Established liability for corporations responsible for hazardous waste sites. Created a trust fund for cleanup if responsible parties for contaminated sites could not be found.

Nuclear Waste Policy Act (1982): Established federal authority to provide locations for permanent disposal of high-level radioactive wastes and required the operators of nuclear power plants to pay the costs of permanent disposal.

Marine Plastic Pollution Research and Control Act (1987): Discharge of plastics into water is prohibited. Food waste, paper, rags, glass, and metal cannot be discharged into navigable water or within 12 miles (19 km) of land.

RELEVANT LAWS (continued)

Medical Waste Tracking Act (1988): Required tracking systems, stringent management standards, packaging, and labeling of medical supplies.

Waste Reduction Act (1990): Requires the EPA to develop and coordinate a pollution prevention strategy and develop source reduction models. Requires owners and operators of manufacturing facilities to report annually on source reduction and recycling activities.

QUICK REVIEW CHECKLIST

- ☐ **Air Pollution**
  - ☐ major air pollutants
    - ☐ nitrogen dioxide
    - ☐ ozone
    - ☐ sulfur dioxide
    - ☐ suspended particulate matter (PM_{10})
    - ☐ volatile organic compounds (VOCs)
  - ☐ measurement units
  - ☐ smog
    - ☐ formation of industrial smog
    - ☐ formation of photochemical smog
  - ☐ acid deposition
    - ☐ causes and effects
  - ☐ heat islands
  - ☐ temperature inversions
  - ☐ indoor air pollution
  - ☐ remediation and reduction strategies
  - ☐ relevant laws and protocols
    - ☐ Air Pollution Control Act (1955)
    - ☐ Clean Air Act (1963)
    - ☐ National Environmental Policy Act (1969)
    - ☐ Clean Air Act (1970)
    - ☐ Montreal Protocol (1989)
    - ☐ Clean Air Act (1990)
    - ☐ Pollution Prevention Act (1990)
    - ☐ Kyoto Protocol

QUICK REVIEW CHECKLIST (continued)

- ☐ **Noise Pollution**
  - ☐ causes
  - ☐ effects
  - ☐ control measures
  - ☐ Noise Control Act (1972)
- ☐ **Water Pollution**
  - ☐ sources
    - ☐ air pollution
    - ☐ chemicals
    - ☐ microbiological
    - ☐ mining
    - ☐ noise
    - ☐ nutrients
    - ☐ oxygen-depleting substances
    - ☐ suspended matter
    - ☐ thermal sources
  - ☐ Minamata disease
  - ☐ *Exxon Valdez* (1989)
- ☐ **Cultural Eutrophication**
- ☐ **Groundwater Pollution**
- ☐ **Maintaining Water Quality and Water Purification**
  - ☐ drinking water treatment methods
  - ☐ water treatment remediation technologies
- ☐ **Sewage Treatment/Septic Systems**
  - ☐ primary treatment
  - ☐ secondary treatment
  - ☐ tertiary treatment
- ☐ **Relevant Laws**
  - ☐ Federal Water Pollution Control Act (1948)
  - ☐ Water Quality Act (1965)
  - ☐ Clean Water Act (1972)
  - ☐ Safe Drinking Water Act (1974)
  - ☐ Ocean Dumping Ban Act (1988)
  - ☐ Oil Spill Prevention and Liability Act (1990)
  - ☐ Source Water Assessment Program SWAP (1966)
  - ☐ Source Water Protection Program SWPP (1996)
  - ☐ Surface Water Treatment Rule SWTR (1996)

QUICK REVIEW CHECKLIST (continued)

- ☐ **Solid Wastes**
  - ☐ different types
    - ☐ organic
    - ☐ radioactive
    - ☐ recyclable
    - ☐ soiled
    - ☐ toxic
  - ☐ amounts and type of MSW
  - ☐ disposal and reduction methods
    - ☐ incineration
    - ☐ composting
    - ☐ remanufacturing
    - ☐ detoxifying
    - ☐ exporting
    - ☐ land disposal—sanitary landfills
    - ☐ land disposal—open dumping
    - ☐ ocean dumping
    - ☐ recycling
    - ☐ reuse
    - ☐ solid waste flow diagram

- ☐ **Relevant Laws**
  - ☐ Solid Waste Disposal Act (1965)
  - ☐ Resource Conservation and Recovery Act (1976)
  - ☐ Toxic Substances Control Act (TOSCA) (1976)
  - ☐ Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA-Superfund) (1980)
  - ☐ Nuclear Waste Policy Act (1982)
  - ☐ Marine Plastic Pollution Research and Control Act (1987)
  - ☐ Medical Waste Tracking Act (1988)
  - ☐ Waste Reduction Act (1990)

MULTIPLE-CHOICE QUESTIONS

1. __________contributes to the formation of __________ and thereby compounds the problem of __________.

   (A) ozone, carbon dioxide, acid rain
   (B) carbon dioxide, carbon monoxide, ozone depletion
   (C) sulfur dioxide, acid deposition, global warming
   (D) nitrous oxide, ozone, industrial smog
   (E) nitric oxide, ozone, photochemical smog